Assessment on the Regulation Improvement of Small and Medium Reactor Design Requirements Based-on Lesson Learned from Fukushima Accident

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Outline

Introduction

SMR

Lesson Learned from Fukushima Accident

Regulatory Improvement

SMR Design Requirements
• Indonesia is a archipelagic country comprising of 17,000 islands stretched over 5200 km from Banda Aceh, on the tip of Sumatra in the west, to the remote highlands of West Papua in the east.
Energy Supply
Source: Energy Outlook – Agency for the Assessment and Application of Technology (2016)
Target of Energy Supply

• Indonesian government is targeting the supply of electrical energy during 2014-2019 of 35,000 MWe.

• The Indonesian Energy and Mineral Resources Ministry (ESDM) in 2016 admitted that only 19,763 MWe of power plant projects will be completed by end of 2019, representing **56.5%** of the target.

• Many experts and institutions claim in their energy outlook that the target can be achieved by the contribution of electricity from nuclear power plants.
Introduction of BAPETEN

(Act no. 10 / 1997):

- BATAN (National Nuclear Energy Agency)
- BAPETEN (Nuclear Energy Regulatory Agency)
  - To regulate the utilization of nuclear energy through managing regulation, licensing and inspection, with the aim to ensure the welfare, security and peace of people, to assure the safety and health of workers and public, and the environmental protection, and to prevent diversion of purpose of the nuclear material utilization
Regulatory Infrastructure in Indonesia

- **MEMR**: Industry, Hospital
- **BATAN**: Nuclear Application:
  - Industrial, and
  - Medical purposes
- **R&D**
- **Other Applications**
- **NPPs**
- **ELECTRIC COMPANY**

- **PRESIDENT RoI**
- **NEC**
- **MoI, MoH, etc.**
- **Industry, Hospital**
- **BAPETEN**
- **BATAN**
- **MEMR**

Nuclear Application:
- Industrial, and
- Medical purposes

R&D

Other Applications

Nuclear Power Plants (NPPs)
The Role of BAPETEN

Nuclear Research Reactors (BATAN)
- RSG-GAS (30 MW)
- TRIGA-2000 (2 MW)
- KARTINI (100 kW)

Medical and Industries
- X-Ray
- Therapy Facilities
- Irradiator
- Radioactive Sources
- etc

TENORM

Nuclear Installations
BATAN
- Nuclear Installations non Reactor
Non-BATAN
- RR Fuel Element Prod. Inst.

Nuclear Materials
In Reactor and Non Reactor

Indonesia
National capital
International boundary
Railroad
Road
2. SMR

- advanced reactors that produce electric power up to 300 MW(e), designed to be built in factories and shipped to utilities for installation as demand arises (IAEA)

- “a small modular reactor needs to be able to offer the advantage of a lower initial capital investment, short construction time, scalability and siting flexibility to include some locations that might be less suitable for conventional nuclear reactors (US-DOE : Burges Salmon)
• The need for flexible power generation for wider range of users and applications
• Replacement of aging fossil-fired units
• Cogeneration needs in remote and off-grid areas
• Potential for enhanced safety margin through inherent and/or passive safety features
• Economic consideration – better affordability
• Potential for innovative energy systems:
  - Cogeneration & non-electric applications
  - Hybrid energy systems of nuclear with renewables

(Source : IAEA)
Light water-cooled SMRs

CAREM-25
Argentina

IMR
Japan

SMART
Korea, Republic of

VBER-300
Russia

WWER-300
Russia

KLT-40s
Russia

mPower
USA

NuScale
USA

Westinghouse
SMR - USA

CNP-300
China, People Republic of

ABV-6
Russia

(Source: IAEA)
Heavy-water cooled SMRs

EC6
Canada

PHWR-220, 540, & 700
India

AHWR300-LEU
India

(Source: IAEA)
Liquid-Metal cooled Fast SMRs

CCFR
China

4S
Japan

PFBR-500
India

SVBR-100
Russian Federation

PRISM
USA

(Source : IAEA)
Gas-cooled SMRs

PBMR
South Africa

HTR-PM
China

GT-MHR
USA

EM²
USA

(Source: IAEA)
# SMRs for Near-term Deployment

<table>
<thead>
<tr>
<th></th>
<th>Name</th>
<th>Design Organization</th>
<th>Country of Origin</th>
<th>Electrical Capacity, MWe</th>
<th>Design Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>System Integrated Modular Advanced Reactor (SMART)</td>
<td>Korea Atomic Energy Research Institute</td>
<td>Republic of Korea</td>
<td>100</td>
<td>Standard Design Approval 2nd Quarter 2012</td>
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<tr>
<td>2</td>
<td>mPower</td>
<td>Babcock &amp; Wilcox</td>
<td>United States of America</td>
<td>160/module</td>
<td>Detailed design, to apply for certification - end of 2012</td>
</tr>
<tr>
<td>3</td>
<td>NuScale</td>
<td>NuScale Power Inc.</td>
<td>United States of America</td>
<td>45/module</td>
<td>Detailed design, to apply for certification - end of 2012</td>
</tr>
<tr>
<td>4</td>
<td>VBER-300</td>
<td>OKBM Afrikantov</td>
<td>Russian Federation</td>
<td>300</td>
<td>Detailed design</td>
</tr>
<tr>
<td>5</td>
<td>SVBR-100</td>
<td>JSC AKME Engineering</td>
<td>Russian Federation</td>
<td>100</td>
<td>Detailed design for prototype construction</td>
</tr>
<tr>
<td>6</td>
<td>Westinghouse SMR</td>
<td>Westinghouse</td>
<td>United States of America</td>
<td>225</td>
<td>Detailed Design</td>
</tr>
<tr>
<td>7</td>
<td>Super-Safe, Small and Simple (4S)</td>
<td>Toshiba</td>
<td>Japan</td>
<td>10</td>
<td>Detailed design</td>
</tr>
</tbody>
</table>

(Source: IAEA)
Key Issues

- First of a kind engineering (operation experience, cost ?)
- Viability of multiple modules per site
- Proliferation resistance and physical security
- Control room staffing
- Emergency planning zone size
- The use of mechanistic source term in modeling of accident consequences
- Use of risk informed licensing method
- Technology transfer and proprietary design protection
Emergency Planning Zone

Regulatory perspective:

• Planning for action undertaken in the event of severe accident
• Provide one of the necessary protection levels in DID strategy
• Learned from Chernobyl and Fukushima, EPZ is still needed even the probability of severe accident is very small -> how small is EPZ?
EPZ, Industry Perspective

- Improved safety of SMRs → lower the size of EPZ: < 500 m
- SMRs are sources for industrial heat: close to other industries
- For district heating, for example, SMRs need to be close to population
- Large EPZ cost increase the total cost of SMR
The emergency planning zone (EPZ) is the distance around a nuclear power plant that has a predetermined emergency plan in place in response to the possibility of a nuclear accident at the plant.

Current Large Light Water Reactors (LLWR) in operation have a 10-mile and 50-mile inhalation and ingestion EPZ distances.

SMR has a lower risk profile than the LLWR plants,

This work is significant to support the cost effectiveness of the future SMR plants.

(Source: Pittsburgh Technical)
Current Issues

(Gen-IV):

- SFR
- LFR
- GFR
- VHTR
- SWR
- MSR

6 INNOVATIVE CONCEPTS WITH TECHNOLOGICAL BREAKTHROUGH

SODIUM FAST REACTOR

LEAD FAST REACTOR

GAS FAST REACTOR

VERY HIGH TEMPERATURE REACTOR

SUPERCRITICAL WATER REACTOR

MOLTEN SALT REACTOR

HTGR-BATAN
MULTI STEPS (5 Steps):

- Site License
- Construction License
- Commissioning License
- Operating License
- Decommissioning License

Before construction license phase, applicant shall apply design approval from BAPETEN Chairman with the requirements:

1. Detail Design of Nuclear Reactor; and
On August 26–27, 1883, the explosion of volcano of Krakatoa generated tsunami waves that were up to 37 m (120 feet) in height, destroyed 295 towns and villages. 36,417 people were drowned.
Lesson Learned from Fukushima Accident

Based on The Fukushima Daiichi Accident STI/PUB/1710 Technical Vol 2 (2015) from I. Assessment of the Plant in Relation to External Hazard

1. The safety of nuclear installations, in general, and the site related aspects, in particular, needs to be reassessed during their operational life in response to new knowledge, new hazards, new regulations and new practices, as part of periodic safety reviews.

2. National and international standards to cope with external events in siting, site evaluation and design aspects need to be periodically updated and revised.

3. Assumptions of complex scenarios need to be made and adequate conservative estimations need to be applied.

4. The assessment of natural hazards needs to be sufficiently conservative based on pre-historic and historical data.

5. Regarding uncertainties in tsunami hazard calculations, special attention needs to be paid to the aleatory and epistemic uncertainties associated with the maximum magnitude earthquake related to tsunamigenic sources such as major subduction zones.
6. There is a need to use a systemic approach in dealing with the design and layout of SSCs for effective protection against flooding hazards.

7. There is a need to act effectively and promptly in implementing upgrading measures to maintain the defence in depth concept of an installation and to ensure the performance of safety functions when an original dry site becomes a wet site during its operational life as result of a reassessment of the flooding hazards at the site.

8. Complex scenarios involving consequential or independent occurrences of multiple external hazards affecting multiple units located on a site and, possibly, multiple NPPs at different sites in the same region need to be considered in accident scenarios and actions to be taken.

9. Clear procedures establishing measures to be taken before, during and after a tsunami, in particular, and for any external event, in general, adopted for design bases need to be prepared, implemented and exercised during the operation of the nuclear installation.
II. Assessment of the Failure to Maintain Fundamental Safety

1. Provisions need to be made for ensuring fundamental safety functions in case of loss of DID Level 3, including core cooling, spent fuel cooling and containment integrity.

2. The assessment of natural hazards needs to be sufficiently conservative based on pre-historic and historical data.

3. Personnel need to be trained to manage severe plant conditions (Level 4).

4. Defence in depth Level 4 provisions need to be independent from those of Level 3.

5. Interconnections between units need to be designed to prevent an accident from migrating from one unit to another.

6. Critical instrumentation needs to be designed and maintained so that it continues to function during severe accidents.

7. Provision needs to be made for the removal of decay heat by alternative means (such as mobile equipment) should the permanently installed equipment not be operable.
III. Assessment of the Treatment of Beyond Design Basis Event

1. Deterministic and probabilistic beyond design basis safety analyses need to be comprehensive and take into account both internal and external events.
2. Extremely low numerical values from PSA s need to be reviewed and confirmed.

IV. Accident Management (AM) Provision and Their Implementation

1. AM provisions need to be clear, comprehensive and well designed.
2. Regulatory bodies need to ensure that adequate AM provisions are in place, taking into account severely damaged infrastructures and long duration accidents.
3. Training and exercises need to be based on realistic severe accident conditions.
4. Provisions for the proper management of hydrogen need to be considered.
4. Regulatory Improvements

- **Regulatory control** is performed through 3 main functions, i.e.: *Regulation, Licensing, and Inspection*.

**Technical Supports**
- provides assessments and recommendations regarding the regulation, licensing, and inspection
**Hierarchy of Law & Regulation**

- **LAW**
  - Government regulations
  - Presidential Decree
  - Authoritative Regulations
    - BAPETEN Chairman Reg.
  - Regulatory Guidelines
    - Licensing
    - Inspections

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**Nuclear Energy Act 10 Year 1997, Chapter II Articles 3**

Basic principles in safety arrangement for the development and beneficial use of nuclear energy.

- Government Regulation on “Licensing of Nuclear Installations and Nuclear Materials Utilizations” No. 2 year 2014
- Government Regulation on “Safety and Security of Nuclear Installations” No. 54 year 2012

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**Regulation based on Law**

- BAPETEN Chairman Regulation (BCR) on “Safety of NPP Design” No. 3 year 2011

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- Main Data Reactor Evaluations Instructions Document
- Safety Analysis Report Evaluations Instructions Document
- Design Nuclear Reactor Inspections Instructions Document
Article 3
This BCR regulates the general requirements, special requirements, hazard monitoring and quality assurance in evaluating the safety of a nuclear reactor site in detail.

Article 9
(2) PET should choose the parameters and parameter values external events or combinations of events that used to characterize the hazard

Article 15
PET must determine the number of units and / or installed power nuclear reactors at the site since the beginning of the process of site selection.

Article 20
(1) PET should specify hazard determination method associated with major external phenomena.
(2) The method as described in paragraph (1) shall be advanced in accordance with the characteristics of the siting candidate, and consider the probabilistic methodology.
Article 31
(1) PET should set the external zone of the tread by considering potential candidates from radiation on the population, the feasibility of implementing the nuclear emergency preparedness program, and each event and / or an external phenomena that may hinder the implementation of the program.

Article 34
(1) The risk of earthquakes should be determined by means of seismotectonic evaluation at site location by using the information referred to in Article 33.

(2) The risk of ground motion caused by an earthquake on the candidate site shall be assessed taking into account the seismotectonic characteristics of the region and site specific conditions.

(3) uncertainty thorough analysis should be carried out as part of the seismic hazard evaluation.

Article 35
(1) PET should examine the potential of active surface faults on the prospective site.
Article 39
(1) PET should investigate extreme values of meteorological variables and rare meteorological phenomenon to the nuclear reactor site.

Article 41
(1) PET shall describe the site evaluation in accordance with the design of nuclear reactors.

Article 51
Meteorological and hydrological models were adequate should be developed taking into account the limits of accuracy and quantity of data, the historical period of data collection, as well as all changes in the characteristics of the past relevant to site area.

Article 57
If there is a potential tsunami or tidal oscillation as referred to in Article 56, the data prehistory and history of tsunamis or tidal affecting coastal areas in the vicinity of the site must be collected and evaluated the relevance and reliability.
Article 60

Hazards associated with tsunamis or tidal oscillation as referred to in Article 56, including the draw-down and the run-up must be determined from seismic records and seismotectonic characteristics are known including analytical modeling and/or physical.

Article 108

PET must establish and implement a quality assurance program to monitor the effectiveness of the implementation of site investigation, site assessments and engineering were performed at different stages in the evaluation of the nuclear reactor site.
BCR 3/2011 provides safety of nuclear power plants design

Article 2:
(1) This BCR aims to provide safety requirements for license holders to ensure the design and safety analysis of the reactor design so that power can be operated safely in all conditions.

(3) The condition of the installation as referred to in paragraph (1) shall include:
a. normal operation;
b. anticipated operational occurrences; and
c. design basis accidents and beyond design basis accidents

Article 3:
The licensee must ensure that the power reactor is designed with a high degree of reliability to achieve the objectives of nuclear safety.

Article 6:
The effective defense which articulated in the Article 5, paragraph 2 above is realized through the implementation of defense in depth to meet basic safety function of the reactor
Article 8:

**Basic safety function** of the reactor as referred to in Article 6 include:

a. controlling the **reactivity**;

b. **transfer heat** from the reactor core; and

c. confine the **radiation** and **radioactive substances**.

Article 9:

(1) Basic of the reactor safety functions referred to in Article 8 must be carried out **during operation status**, **during and after going DBA**, and **accidents that exceed the specified DBA**.

Article 13:

- **Conservative design** should be applied, and good engineering practices must be followed for the entire power reactor operating conditions so as to ensure there is no significant damage to the reactor core and radiation exposure remains below the limiting value.
Article 31

(1) Power reactor should be designed to consider the operator actions that may be needed to diagnose the state of the installation and to shutdown at the right time.

(2) To support the operator actions, the design should provide instrumentation system for monitoring the state of the installation and control the operation of the equipment manually.

Article 33

(1) Power reactors must be designed to anticipate accidents beyond the design basis and severe accidents through prevention and mitigation measures.

(2) In anticipation of accidents as referred to in paragraph (1), should be considered:
Article 33 (2) continued

a. identification of the sequence of important events that tend to accident through a combination of probabilistic methods, deterministic, and includes technical considerations;

b. Assessment of the sequence events as described in the a based on the established criteria to determine the accident, Earthquake then tsunami;

c. evaluation of potential design changes or procedural changes that can reduce the probability of occurrence or mitigate the consequences of accidents were determined as described in paragraph b;

d. Maximum design capabilities including the use of reactor safety systems and other systems which go beyond its functions, as well as the use of an additional system to restore the installation to a controlled state and or mitigate the consequences of severe accidents;

e. ……

f. determination of accident management by considering the most dominant accident.
Reason of improvement as follows:

- NS-R-1 has been revised to IAEA SSR-2/1
- Safety aspects of nuclear reactors after Fukushima accident related to the site evaluation and plant design requirements
- Several current issues, i.e. BATAN planned to construct HTGR in Indonesia
1. The safety of nuclear installations, in general, and the site related aspects, in particular, needs to be reassessed during their operational life.

2. The assessment of natural hazards needs to be sufficiently conservative based on pre-historic and historical data and considering the uncertainty approach in computation.

3. Deterministic and probabilistic beyond design basis safety analyses need to be comprehensive.

4. Determining the appropriate emergency planning zones considering the graded approach;

5. The need for a clear definition and interpretation of the state of the plant (NO, AOO, DBA, DEC), in both the reactors and the spent fuel storage pool,
6. The need for emphasizing the independence of safety systems at different levels of defense in depth,
7. The need for the prevention of common cause failure,
8. Interconnections between units need to be designed to prevent an accident from migrating from one unit to another for multi units of SMR -> probabilistic computation using Bayesian approach
9. The need for an emphasis on design against extreme external hazards,
10. The condition of station blackout and use of mobile resources either in the form of electric power supply and cooling source should be taken into account
11. The mitigation measures for severe accidents and training should include procedure of implementation should be taken into account
1. Lesson learned from Fukushima accident shows that the regulator should be proactive to **improve the regulation** based on the exchange of experience from other countries or IAEA documents revision.

2. SMR as an ultimate hope for energy supply in the continent countries should be **designed** based on the lesson learned from Fukusima accident.

3. The appropriate **emergency planning zones** should be determined considering the graded approach to optimized the cost.

4. Propagation of accident from **sequence events** should be considered to prevent an accident from migrating from one unit to another for multi units of SMR.
Thank you